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Comparative Study of Cost and Eco-Efficiency Factors of Aluminum and Conventional Formwork in The AYOMA Apartment Construction Project

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ABSTRACT

The AYOMA Apartment construction project used two types of formwork; both aluminum formwork and conventional formwork are applied on one floor. A comparison of the costs of the two types of formwork used has not been carried out in the project planning. This study aimed to obtain a comparison between aluminum formwork and conventional formwork in terms of cost and eco-efficiency factors. The comparison was made specifically on the formwork of the 3rd Floor of the West Tower, The AYOMA Apartment. The unit price analysis of formwork was based on the coefficient of each work item following the regulation on Unit Price Analysis of Public Works and unit price standards applicable in the project location area. The eco-efficiency factors were calculated from the waste produced by manpower. The calculation results showed that the cost of aluminum formwork for the 3rd Floor of West Tower of The AYOMA Apartment is IDR 2,708,328,757.73 or 2.25 times higher than the conventional formwork cost of IDR 1,204,987,034.60. However, when the reusability factor was considered, aluminum formwork is up to 14.83 times more efficient than conventional formwork. In the eco-efficiency factors analysis, the waste produced by manpower for the work of aluminum formwork is less, only 56.48% of the waste produced by manpower for the work of conventional formwork. The amount of waste produced from the main material and the quality of concrete produced by using aluminum formwork support the conclusion that aluminum formwork is more eco-efficient than conventional formwork.

Keywords: *Aluminium Formwork;Conventional Formwork; Cost Comparison; Eco-Efficiency*

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INTRODUCTION

The implementation of construction projects requires project management to ensure the level of effectiveness and efficiency of the works carried out on the project, to achieve the objectives optimally. All planning, execution, control, and coordination of a project from the beginning (idea) to the end of the project is a function performed by project management to ensure the implementation of the project takes place on time, on cost, and on quality [1]. The scope of project management work includes physical construction quality, cost, time, labor management, and material management; including the selection of formwork materials.

In the construction of a building, contractors always need formwork to cast concrete. Formwork is a temporary mold used to bear the load during which the concrete is poured and moulded according to the desired shape. Due to its function as a temporary mold, the formwork will be removed or dismantled when the concrete has dried up and reached sufficient strength

[2]. Formwork is a temporary construction that has three main functions, i.e.: 1) To mould the shape of concrete to be made, 2) To obtain the expected concrete surface structure, and 3) To withstand concrete until the construction is strong enough to withstand its own load, equipment, and labor [3].

Good formwork material is one that meets several requirements. The formwork material should have good quality in terms of strength, durability, and rigidity, should be safe for workers and concrete structures, should possess good efficiency in operation, easy to handle, and dismantle, and should be economical. It also should be strong enough to withstand the dead and live load [4]. Good formwork material should be leak-proof to prevent liquid concrete leakage, should be able to be set accurately to the desired line, should not warp or get distorted when exposed to the elements, not suck water from the concrete mixture, has the desired texture, and exact dimensions. In addition, cleanliness in formwork should be checked before pouring concrete; formwork should be adjustable and removable without damaging the concrete [2].

In the implementation of a construction project, especially in building construction, formwork is one of the three Pareto items or items that are most influential in the sustainability of structural work, besides steel and cast work. In Indonesia, conventional formwork made of wood is still more widely used than aluminum formwork. However, other types of formwork began to be widely used, mainly due to the increasing environmental awareness, including in the field of construction. In the construction project of The AYOMA Apartment located in Serpong, South Tangerang City, Banten Province, two types of formwork – conventional and aluminum – are used together on one floor. However, in the project planning, there was no calculation or budget comparison of the two types of formwork used, especially in terms of cost and eco-efficiency factors.

Formwork Planning

Formwork use planning in construction work is a big responsibility for the contractor. Several objectives must be considered in choosing and designing formwork, i.e.: 1) Quality: formwork must be designed and made with stiffness and accuracy so that the shape, size, position, and finishing of the casting can be carried out as desired, 2) Safety: formwork must be erected with sufficient strength and safety factors to be able to withstand all death and life loads without collapsing or being harmful to workers and ongoing concrete construction; and 3) Economical: formwork must be made efficiently, minimizing time and cost in the implementation process for the benefit of the contractor and owner [5].

Type of Formwork

Wigbout distinguishes formwork into 3 groups, i.e. [3]:

1. Conventional formwork: the main materials are wood, multiplex, and board. This formwork material is easy to obtain and has high flexibility, but the resulting shape is often not precise so it requires rework, is not durable for repeated use, long installation time, and produces a lot of wood and nail waste.
2. Semi-modern formwork: the main material is a combination of wood and fabricated materials. Wood is used only on certain parts, using plywood material.
3. Modern formwork: all materials are fabricated materials. Most components are made of steel and are intended for repeated use. This formwork can also be used for several different jobs. The installation is simplified so that the technical implementation becomes easier. This type of formwork has considered the eco-efficiency aspect. However, the initial cost

of this formwork is generally much more expensive than conventional formwork. Aluminum formwork is one example of this type of formwork.

Unit Price Analysis (AHSP)

The unit price of construction work can be calculated in a way known as Unit Price Analysis (AHSP). The calculation is described by multiplying the needs of building materials, labor wages, and equipment by material prices, standard labor wages, and rent/purchase prices for equipment to complete each unit of construction work. AHSP is the sum of material prices and labor wages based on calculations analysis of each work item [6]. The difference in materials market price and labor wages that are applicable in each region causes the difference in unit price from one region to another. It means that the calculation of the project budget plan and cost must be based on the market price of materials and labor wages at the project location. For each type of work that has been detailed in the project plan, the unit price of the work must be calculated according to the amount, type, and specifications of the material, as well as the number of workers that will be needed, including for formwork work.

Eco-Efficiency Principle

Eco-efficiency is defined as the delivery of competitively priced goods and services that satisfy human needs and enhance the quality of life while progressively reducing ecological effects and resource intensity throughout product life cycles to a level appropriate with the estimated capacity of the earth (Kibert 2008) [7]. In a construction process, unused materials will be wasted and become garbage. This waste will cause an increase in social costs for the follow-up process and can harm the environment. By increasing efficiency, more materials will be used in the construction process, and less will be wasted. Therefore, the principle of eco-efficiency is to try to minimize the level of materials and energy that will be wasted so that the production or construction process becomes more efficient [8]. The concept of eco-efficiency in the building construction process refers to processes that seek to maximize the effectiveness of the construction process while minimizing its impact on the environment, including efforts to reduce waste production from construction work [9].

Related to the project management function, to ensure the efficiency and effectiveness of all work in construction projects, it is necessary to know the level of cost efficiency of each choice in the project site, including the choice of formwork materials used. The increasing awareness to use more environmentally friendly materials is the basis to find out the level of eco-efficiency of materials. This study aims to determine the comparison of cost and eco-efficiency factors between aluminum formwork and conventional formwork on the formwork work of The AYOMA Apartment, Serpong.

METHODS

The calculation of formwork costs is carried out on the formwork of the 3rd Floor of the West Tower of The AYOMA Apartment because on that floor 2 types of formwork are used together at once and the floor plan is typical with all the floor plans above. The 1st Floor and 2nd Floor are podium buildings and the contractor uses only 1 type of formwork on those floors. The calculation was based on the shop drawing provided by the contractor.

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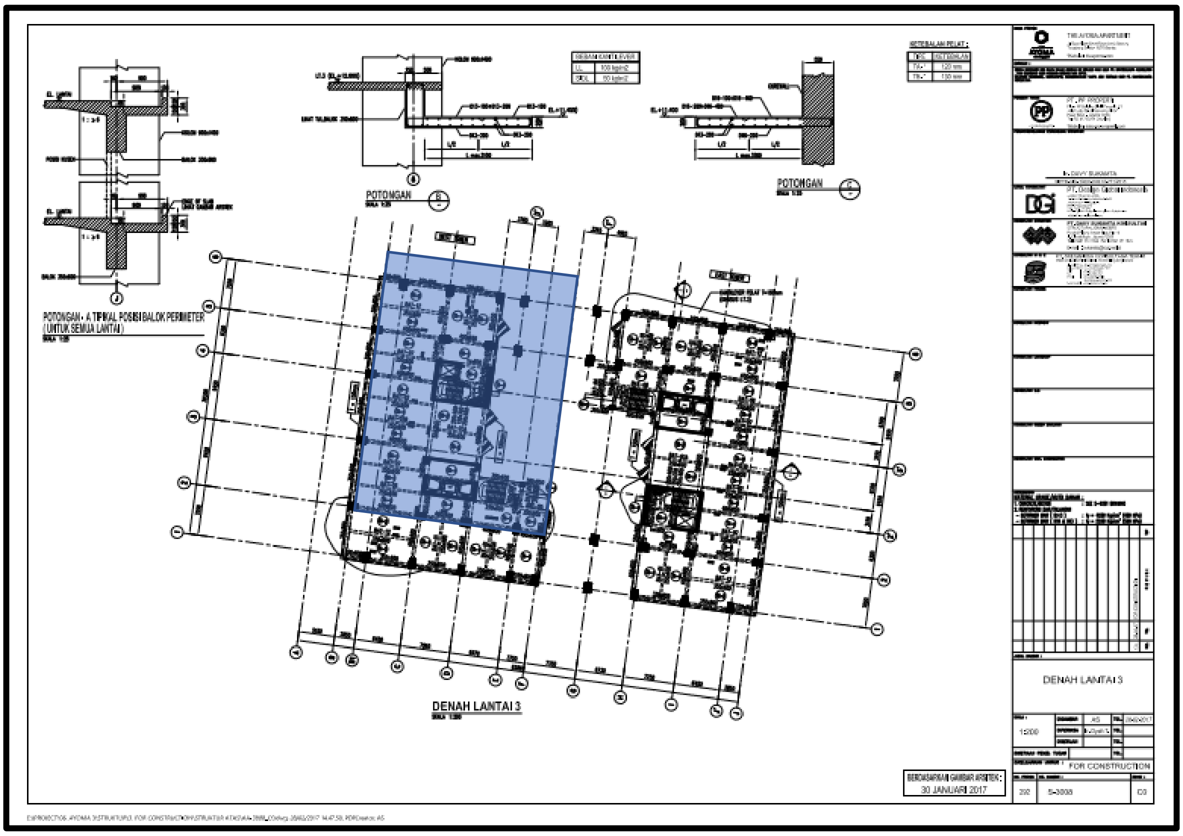

Figure 1. 3rd Floor Plan of West Tower

Formwork Work Unit Price Analysis

The unit price used in the unit price analysis of conventional formwork was the unit price applicable in the Jabodetabek area (Jakarta, Bogor, Depok, Tangerang, and Bekasi) at the time of project implementation Analysis of the unit price of the work was based on the Regulation of the Minister of Public Works and Public Housing applicable at the time of project implementation [10]. The coefficient for each item of conventional formwork work referred to the calculation tables in the regulation. However, in this regulation, there is no Unit Price Analysis (AHSP) for aluminum formwork. Therefore, the unit price analysis of aluminum formwork was based on information from the contractor [11]. The unit price used was the average cost of aluminum formwork per m2 at the time of project implementation.

Formwork Work Volume Calculation

The volume of column formwork work is calculated by using Formula 1:

$$[(2 \times Lc \times Hc)+(2 \times Wc \times Hc)] \times \sum c \quad (1)$$

Lc = length of column
Hc = height of column
Wc = width of column
∑c = total number of column

Beam formwork work is related to slab formwork work. The height of the beam formwork on the long side will be reduced by the height of the slab because that side meets the lower slab formwork. As for the wide side of the beam, there is no formwork because its surface meets

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the column surface on that side. The volume of work of beam formwork is calculated by using Formula 2:

[(2 x W b x H b f)+(1 x Lb x Wb)] x ∑b.. (2)

Hbf = height of beam formwork (height of beam minus height of slab)

Wb = width of beam

∑b = total number of beam

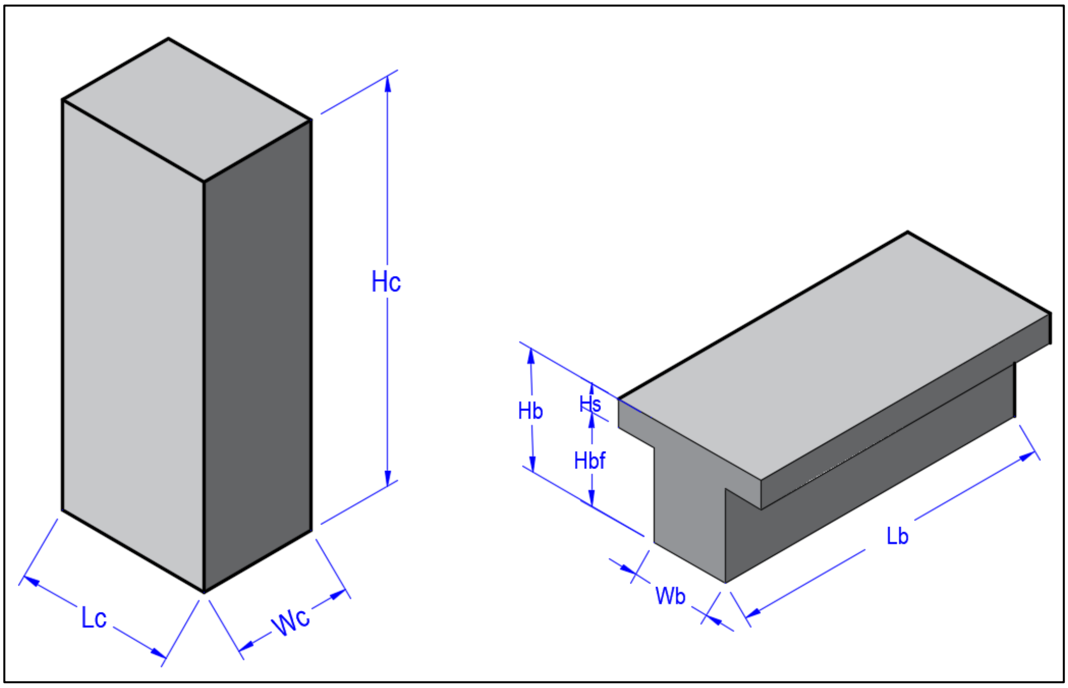

Figure 2. Sketch of the basis of the volume calculation for column formwork (left) and beam formwork (right)

The volume calculation of slab formwork work consists of the calculation of the bottom surface area and the slab edge area of the entire 3rd Floor of West Tower, reduced by the area of the column base and the area of the beam top surface. The edge area of the slab was also taken into volume calculation of slab formwork because the edge of the slab is in the form of an overhang (see Figure 3). The volume of work of slab formwork is calculated by using Formula 3, 4, 5, and 6:

1. Slab Edge Area = Overall Slab Length x Slab Height...3)
2. Column Base Area = (Lc x W c) x ∑c .... (4)
3. Beam Top Surface Area = (Lb x W b) x ∑b .... (5)
4. Slab Formwork Work Volume:
   Slab Area + Slab Edge Area – (Column Base Area + Beam Top Surface Area)............. (6)

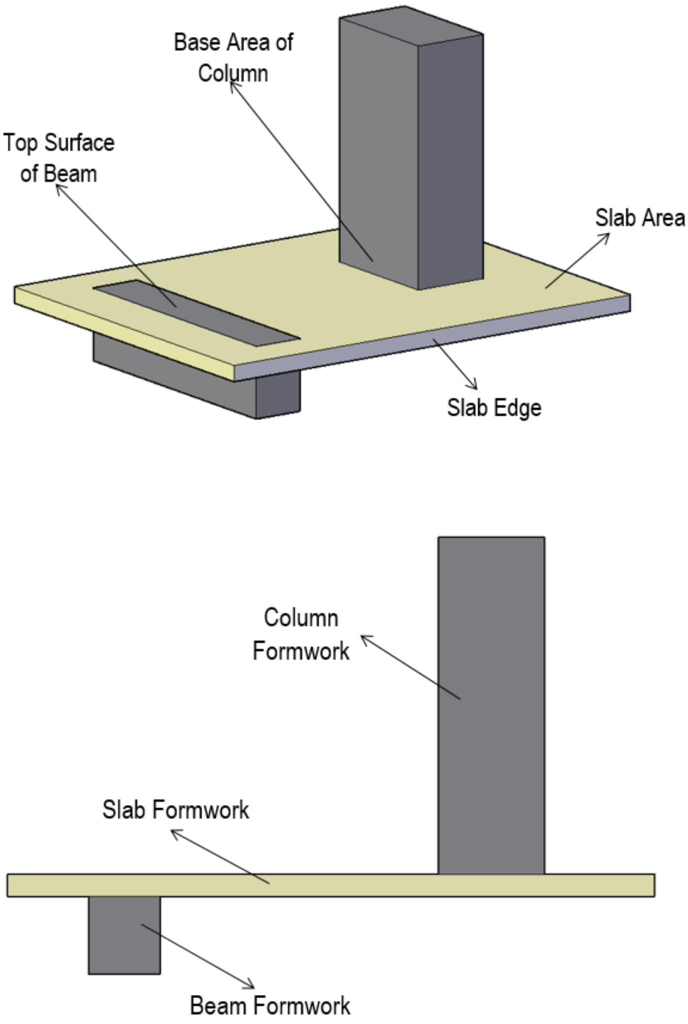

Figure 3. Sketch of the Basis of the Volume Calculation for Slab Formwork

Eco-Efficiency Factors Analysis

Eco-efficiency factors were analyzed through the calculation of waste produced by manpower. The amount of manpower needed for the installation of formwork will affect the amount of waste produced by workers.

RESULTS AND DISCUSSION

Formwork Work Volume

The results of the calculation of column formwork work volume are presented in Table 1.

Table 1. Calculation of column formwork work volume

No	Column Type	Wc	Lc	Hc	∑c	Work Volume (m2)
1	1000x1400	1	1,4	3,5	2	33,60
2	900x1400	0,9	1,4	3,5	18	289,80
3	500X750	0,5	0,75	3,5	1	8,75
Total						**332,15**

The results of the calculation of beam formwork work volume are presented in Table 2.

Table 2. Calculation of beam formwork work volume

No	Beam Type	Wb	Hb	Hs	Hbf	Lb	∑b	Work Volume (m2)
1	400x600	0,4	0,6	0,14	0,46	2,725	2	7,19
		0,4	0,6	0,14	0,46	2,85	4	15,05
		0,4	0,6	0,14	0,46	4,15	2	10,96
		0,4	0,6	0,14	0,46	2,53	2	6,68
		0,4	0,6	0,14	0,46	2,675	1	3,53
		0,4	0,6	0,14	0,46	4,325	1	5,71
		0,4	0,6	0,14	0,46	4,11	1	5,43
2	350x800	0,35	0,8	0,14	0,66	1,35	1	2,25
		0,35	0,8	0,14	0,66	3,035	1	5,07
		0,35	0,8	0,14	0,66	3,025	1	5,05
		0,35	0,8	0,14	0,66	2,835	1	4,73
		0,35	0,8	0,14	0,66	4,48	1	7,48
		0,35	0,8	0,14	0,66	4,275	2	14,28
		0,35	0,8	0,14	0,66	2,7	1	4,51
		0,35	0,8	0,14	0,66	4,47	1	7,46
		0,35	0,8	0,14	0,66	2,825	1	4,72
		0,35	0,8	0,14	0,66	3,105	1	5,19
		0,35	0,8	0,14	0,66	1,275	1	2,13
3	300x800	0,3	0,8	0,14	0,66	0,96	1	1,57
4	550x600	0,55	0,6	0,14	0,46	1,274	4	7,49
5	200x800	0,2	0,8	0,14	0,66	3,3	1	5,02
6	200X500	0,2	0,5	0,14	0,36	1,5	1	1,38
7	500x600	0,5	0,6	0,14	0,46	4	1	5,68
8	BAT - 01	0,25	0,6	0,14	0,46	3,35	3	11,76
9	BAT - 02	0,25	0,6	0,14	0,46	4,685	1	5,48
10	BAT - 03A	0,25	0,6	0,14	0,46	3,425	1	4,01
11	BAT - 03B	0,25	0,6	0,14	0,46	4,685	1	5,48
12	BAT - 04	0,35	0,8	0,14	0,66	1,65	1	2,76
13	BAT - 05	0,35	0,8	0,14	0,66	1,275	1	2,13
14	BAT - 06	0,25	0,6	0,14	0,46	4,735	1	5,54
15	BAT - 07	0,25	0,6	0,14	0,46	4,735	1	5,54
		0,25	0,6	0,14	0,46	4,485	1	5,25
16	BAT - 08	0,25	0,6	0,14	0,46	3,16	1	3,70
		0,35	0,6	0,14	0,46	4,69	1	5,96
		0,35	0,6	0,14	0,46	4,6	1	5,84
Total								**201,98**

The volume of slab formwork work was calculated by first calculating the area of the column base, the area of the beam top surface, and the area of the slab edge.

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Table 3. Calculation of the area of the column base

No	Column Type	Lc	Wc	∑c	Area (m2)
1	1000x1400	1,4	1	2	2,80
2	900x1400	1,4	0,9	18	22,68
3	500X750	0,75	0,5	1	0,38
	Total				**25,86**

Table 4. Calculation of slab top surface area

No	Beam Type	Lb	Wb	∑b	Area (m2)
1	400x600	2,725	0,4	2	2,18
		2,85	0,4	4	4,56
		4,15	0,4	2	3,32
		2,53	0,4	2	2,02
		2,675	0,4	1	1,07
		4,325	0,4	1	1,73
		4,11	0,4	1	1,64
2	350x800	1,35	0,35	1	0,47
		3,035	0,35	1	1,06
		3,025	0,35	1	1,06
		2,835	0,35	1	0,99
		4,48	0,35	1	1,57
		4,275	0,35	2	2,99
		2,7	0,35	1	0,95
		4,47	0,35	1	1,56
		2,825	0,35	1	0,99
		3,105	0,35	1	1,09
		1,275	0,35	1	0,45
3	300x800	0,96	0,3	1	0,29
4	550x600	1,274	0,55	4	2,80
5	200x800	3,3	0,2	1	0,66
6	200X500	1,5	0,2	1	0,30
7	500x600	4	0,5	1	2,00
8	BAT - 01	3,35	0,25	3	2,51
9	BAT - 02	4,685	0,25	1	1,17
10	BAT - 03A	3,425	0,25	1	0,86
11	BAT - 03B	4,685	0,25	1	1,17
12	BAT - 04	1,65	0,35	1	0,58
13	BAT - 05	1,275	0,35	1	0,45
14	BAT - 06	4,735	0,25	1	1,18
15	BAT - 07	4,735	0,25	1	1,18
		4,485	0,25	1	1,12
16	BAT - 08	3,16	0,25	1	0,79
17	BAT - 12	4,69	0,35	1	1,64
		4,6	0,35	1	1,61
	Total				**50,02**

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Slab edge area = total slab length x slab height = 139.37 x 0.14 = 19.51 m²
Volume of slab formwork work = 869.67 + 19.51 - (25.86 + 50.02) = 813.30 m²

Estimation of Formwork Cost

1. Conventional Formwork

Table 5. Estimation of Conventional Formwork Costs

No	Types of Jobs	Volume (v)	Unit	Unit Price (h)	Sum = v x h
1	Installation of conventional formwork for columns	332,15	m²	IDR 824,046.19	IDR 273,706,940.35
2	Installation of conventional formwork for beams	201,98	m²	IDR 853,647.19	IDR 172,416,645.05
3	Installation of conventional formwork for slabs	813,30	m²	IDR 853,647.19	IDR 758,863,449.20
Total		**1.347,43**	m²		IDR 1,204,987,034.60

2. Aluminum Formwork

Table 6. Estimation of Aluminum Formwork Cost

No	Types of Jobs	Volume (v)	Unit	Unit Price (h)	Sum = v x h
1	Installation of aluminum formwork for columns	332,15	m²	IDR 2,010,000.00	IDR 667,621,500.00
2	Installation of aluminum formwork for beams	201,98	m²	IDR 2,010,000.00	IDR 405,972,704.70
3	Installation of aluminum formwork for slabs	813,30	m²	IDR 2,010,000.00	IDR 1,634,734,553.03
Total		**1.347,43**	m²		**IDR 2,708,328,757.73**

Analysis of Eco-Efficiency Factors

The installation of aluminum formwork requires less manpower compared to the installation of conventional formwork; extra carpenters are needed for the installation of conventional formwork. The amount of manpower required for the installation of this formwork affects the amount of waste produced by workers. Table 7 presents a comparison of several factors in aluminum formwork and conventional formwork related to eco-efficiency factors.

Table 7. Comparison of Conventional Formwork and Aluminum Formwork [11]

Variable	Conventional Formwork	Aluminum Formwork
Installation Speed	7-8 days (Floor to floor)	5-7 days (Floor to floor)
Quality	Less neat/smooth concrete	Neat and smooth concrete
Safety (HSE)	Re-shoring	Fix shoring
Waste	A lot of wood and nail waste	The main material does not produce waste
Reusable	4-6 Times	150-200 times
Manpower	Need carpenter and sawyer (70-80 workers/1000 m²)	No special skills required (40-45 workers//1000 m²)

From the table, it can be seen the difference in the needs of manpower in the installation of the two types of formwork. If the amount of manpower needed based on the total area of formwork was calculated by using the highest assumption, the amount of waste produced by workers in the installation of formwork on the 3rd Floor can be calculated. The total area of the 3rd Floor formwork (column, beam, and slab formwork) is 1,347.43 m2. The assumption of waste produced by each worker is 0.75 kg/day.

Table 8. Comparison of the Amount of Waste Produced by Manpower

Factor	**Conventional Formwork**	**Aluminum Formwork**
Manpower	80 x (1347.43/1000) = 108 workers	45 x (1347.43/1000) = 61 workers
Waste Production (assumption 0.75 kg/day)	81 kg	45.75 kg

From the results of the calculation above, the comparison of several factors of these two types of formwork is presented in Table 9.

Table 9. Comparison of Conventional Formwork and Aluminum Formwork

Factor	Conventional Formwork		Aluminum Formwork	
Initial Cost	Lower	(+)	Higher	(-)
Reusability	Lower	(-)	Higher	(+)
Manpower Need	Lower	(-)	Higher	(+)
Eco-friendly Factor	Lower	(-)	Higher	(+)
Processing Time	Slower	(-)	Faster	(+)
Quality of Concrete Produced	Lower	(-)	Higher	(+)
Construction Safety (HSE)	Less Secure	(-)	More Secure	(+)

CONCLUSION

The calculation results showed that aluminum formwork costs IDR 2,708,328,757.73 or 2.25 times higher than the conventional formwork cost of IDR 1,204,987,034.60. However, for the reusable factor, aluminum formwork can be used up to 200 times or 33.33 times more than conventional formwork which can only be used up to 6 times. If the waste factors (damage during installation and disassembly) are not taken into account, then from this combination of price and reusability, aluminum formwork is up to 614.83 times more efficient than conventional formwork.

For the eco-efficiency factors, the waste produced by manpower for aluminum formwork installation is less, only 56.48% of the waste produced by manpower for conventional formwork installation. Another advantage is that aluminum formwork does not produce waste and the quality of the concrete produced is neater and smoother so it does not require rework or repair. Thus, the level of eco-efficiency of aluminum formwork is higher than that of conventional formwork.

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